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Using Line Intersect Sampling for Coarse Woody Debris: Practitioners' Questions Addressed

By P.L. Marshall, G. Davis, and S.W. Taylor

INTRODUCTION

Coarse woody debris (CWD) is an important structural component of forested ecosystems because of its links to biodiversity and to ecosystem processes. CWD is usually described as dead, non-self-supporting, woody material in various stages of decomposition, located above the soil.[1] While a minimum diameter of 10 cm is commonly used to separate CWD from fine woody debris, this parameter may vary with study objectives. In some cases, CWD is defined based on minimum piece diameter and length (e.g., >10 cm in diameter and >1.5 m in length).

Line intersect sampling (LIS) is probably the most common method used to sample dispersed CWD in British Columbia.[2] LIS is simply a means of selecting CWD sample pieces from a population. Its most common application has been for estimating total volume or biomass of woody debris from diameter measurements taken at the points where CWD pieces cross individual transect lines. However, depending on the measurements taken, LIS can also be used to estimate average piece volume, total and average piece biomass, piece length, surface area, and the number of CWD pieces per hectare (density) and cover for an area. This extension note provides answers to some questions posed by field practitioners who use LIS for CWD. This note should be considered supplementary to previous publications on this subject, such as:

- sampling design – Freese (1971), de Vries (1986), and Nemec and Davis (2002); and
- LIS field application – van Wagner (1968), Brown (1974), Taylor (1997), and Marshall et al. (2000).

Therefore, it is assumed that practitioners using this document have experience in basic sampling design and field application of LIS. Although this document is specifically written for the British Columbia situation, it should have general applicability in other jurisdictions.

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[1] In some instances the definition of CWD includes upturned roots and stumps (BC Ministry of Forests 2000a). If this is the case, the bole and root wad should be treated as two measurement groups. The root wad can be defined as the volume of wood below the point of germination (POG) or high side, whichever is higher (BC Ministry of Forests 2000b). In contrast, the CWD or bole wood can be defined as the portion of the tree bole between POG or high side (whichever is higher) and the small end of the piece (Marshall and Davis 2002). In this document, only bole measurements are considered.

[2] The volume of CWD accumulations in landing piles or windrows is often estimated from equations for the volume of an appropriate solid and a ratio estimator to adjust pile volume to wood volume (Little 1982; Hardy 1996).

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Nine questions about the design of cutblock or stand-level surveys of dispersed CWD are addressed in this document. Issues related to the assessment of accumulations (piles) of CWD are not addressed.

The survey design questions are:

Question 1. When many CWD pieces are roughly parallel to each other, what transect orientations should be chosen?

Question 2. What measurements are required to estimate the total cover and surface area of CWD?

Question 3. What measurements are required to estimate the total length of CWD on an area?

Question 4. How should changes in CWD through time be assessed?

The field measurement questions are:

Question 5. Can the transect length be extended to ensure a minimum number of pieces are sampled?

Question 6. What diameter should be recorded for pieces with butt flare?

The data compilation questions are:

Question 7. How can volume-per-hectare estimates for round or semi-round pieces and odd-shaped pieces be combined?

Question 8. Can the number of CWD pieces per hectare or average length of odd-shaped pieces be calculated?

Question 9. How can data be compiled if transects of different lengths are used?

A summary of some commonly used equations for round and semi-round pieces is provided in Appendix A.

SURVEY DESIGN QUESTIONS

Question 1. When many CWD pieces are roughly parallel to each other, what transect orientation should be chosen?

Most disturbances are unlikely to produce CWD pieces that are exactly parallel to each other in orientation. Natural situations where more of the pieces run roughly parallel than could be caused by chance include windthrow on a steep slope, wind effects adjacent to major snow slides, and windthrow resulting from gale force winds. Some types of mechanized and cable harvesting may also cause this effect.

Our advice in these situations is to follow the standard approach: choose the orientation of each transect randomly. If a transect shape other than a straight line (e.g., L-shaped, triangular-shaped) is used, choose the orientation of the first leg at random, and determine the orientation of the other legs according to the shape being used. If an L-shaped transect is to be used, choose the orientation of the first leg at random and then add 90 degrees to this orientation for the second leg. Over the course of a number of sample points, one would expect piece orientations relative to the randomly positioned transect lines to be approximately uniformly distributed over all angles (i.e., 0–180°).

If you are limited by time or money (or the size of the area) to establishing only a few sample points, you cannot rely on the "law of averages" to even things out. In such cases, using an L-shaped transect may be better than using a straight transect.[3]

In certain situations pieces lying parallel to each other occur in clumps (i.e., windfall patches) and can be identified within a larger cutblock or stand prior to sampling (e.g., through aerial photographs). If this is the case, the larger area should be stratified, and the clumps sampled independently (using different sampling methods if desired). The estimates from the dispersed and clumped areas can be subsequently combined using standard stratified random sampling procedures (e.g., Cochran 1977, pp. 89–114). Often, such stratification is expensive or otherwise difficult to do (e.g., no recent aerial photographs, windfall patches are quite small and scattered). In these cases, we suggest proceeding with your sampling scheme irrespective of where your sampling point may fall. However, you can lighten the workload in areas with heavy CWD loading by objectively choosing only a portion of the transect line to sample.[4]

Question 2. What measurements are required to estimate the total cover and surface area of CWD?

Total cover

Total cover refers to the total proportion of the ground area covered by CWD. Overlap between individual pieces is netted out. Total cover can be expressed as a percentage or as cubic metres per hectare. Further, total cover may refer to all pieces or to pieces with specific attributes (e.g., diameter, length, decay class). There are several ways to assess total cover of CWD using LIS. We will address three commonly used approaches.

In the *first approach*,[5] the length of a transect crossing a CWD piece or multiple CWD pieces is recorded. As shown

[3] Analysis of the potential effects of piece orientation on the accuracy of line intersect sampling can be found in Van Wagner (1968), Howard and Ward (1972), and Hazard and Pickford (1986).

[4] Such an approach is described in the *Vegetation Resources Inventory Ground Sampling Procedures* (BC Ministry of Forests 2000a). The key to avoiding bias when reducing the portion of the transect line that is measured in heavy CWD areas is to establish procedures that are independent of the CWD conditions at a sample point. Such procedures should involve: guidelines for when to sample only a portion of the transect line, and guidelines for determining what portion of the transect line will be sampled.

[5] This approach is unbiased for pieces of any arbitrary shape (Lucas and Seber 1977; Kaiser 1983).

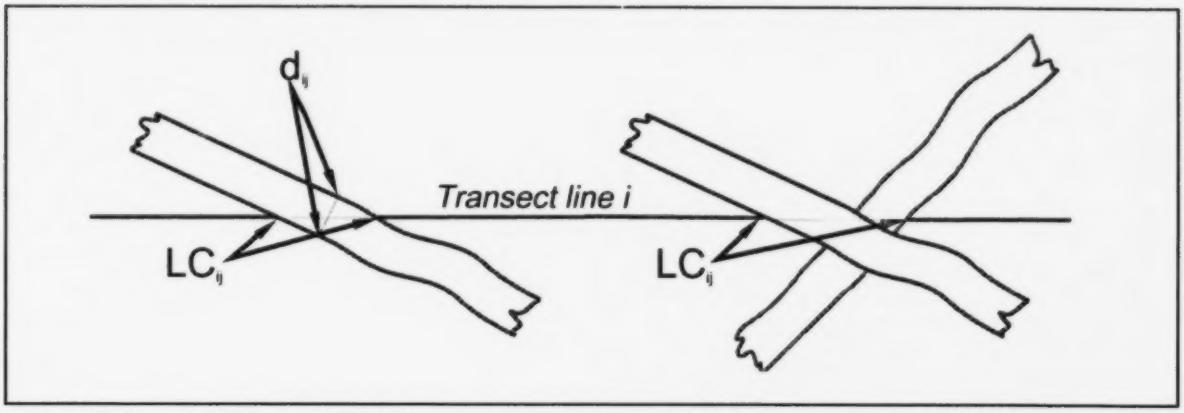

Figure 1. Left: Length of transect crossing a single piece (LC_{ij}) versus the diameter (d_{ij}) that would be recorded for a CWD piece. Right: LC_{ij} that would be recorded for two overlapping CWD pieces.

in **Figure 1**, the length of transect crossing one or more CWD pieces (LC_{ij}) is recorded for all intersections j along line i, in addition to (or instead of) the diameters of the pieces at the points crossed by the transect. In this way, the overlap of individual pieces is not counted more than once. The sum of the transect lengths that have crossed CWD can be expressed as a percentage of the total length of the transect line. Or, total cover can be expressed by multiplying the percentage by 10 000 to convert it to a square-metres-per-hectare basis.

Let LC_i ($=\sum LC_{ij}$) be the length of the transect line at sample point i (of n sample points in total) that has CWD beneath it, and let LB_i be the length of the transect line at sample point i that has bare ground beneath it. $LCi + LBi = L$, the length of the transect line at a sample point. The percent of CWD cover at sample point i is:

$$pc_i(\%) = \frac{LC_i}{L} \times 100. \qquad (1)$$

The average percent of CWD cover is:

$$\overline{pc}(\%) = \frac{\sum_{i=1}^{n} pc_i}{n} \qquad (2)$$

with an estimated standard error of

$$S_{\overline{pc}}(\%) = \sqrt{\frac{\sum_{i=1}^{n}(pc_i - \overline{pc})^2}{(n-1)\times n}}. \qquad (3)$$

If A is the total area of interest (in m^2), then the total CWD cover is:

$$ac(m^2) = \frac{\overline{pc} \times A}{100} \qquad (4)$$

and its standard error is

$$S_{ac}(m^2) = \frac{S_{\overline{pc}} \times A}{100}. \qquad (5)$$

In the *second approach*, percentage cover is determined as the percentage of points that intersect CWD pieces given some number (N) of randomly or systematically established points (**Figure 2**). For example, points can be established at fixed distances along transect lines. The estimated percentage cover is equal to:

$$pc_i(\%) = \frac{m_i'}{N} \times 100 \qquad (6)$$

where,

m_i' is the number of intersections of CWD pieces that occurred among N points along a transect line.

The mean and standard error are calculated similarly to the proportions in the first method. This is an efficient means of estimating cover where it is the only measure of interest because it can be done with a simple tally of intersections; however, it is the least precise of the three methods.

In the *third approach* (as described in Marshall et al. 2000, p. 20), the projected area or "footprint" of each CWD piece crossed by the transect line is estimated. In theory, this requires multiplying the diameter at the point of intersection by the length of the piece (i.e., the area of a rectangle). In practice, a length measurement is not required because piece length appears in both the numerator and the denominator of the equation and length cancels out. Where pieces are highly dispersed and over-

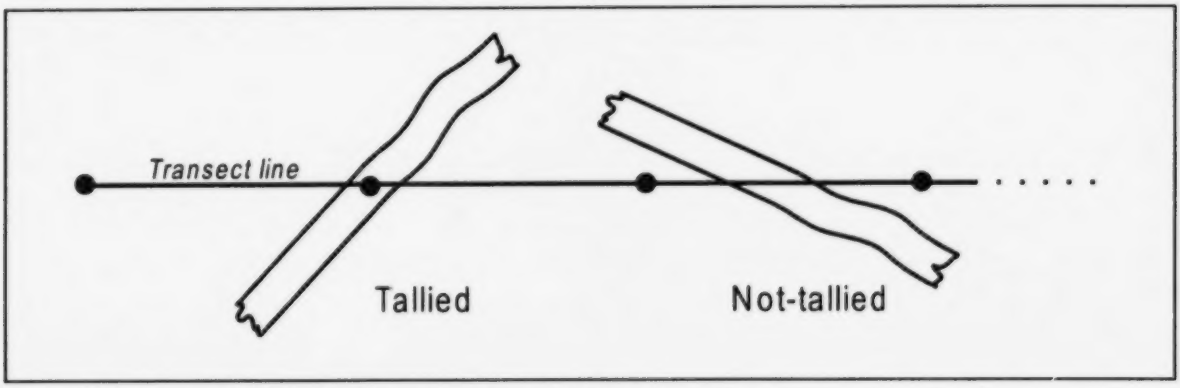

Figure 2. Illustration of tallying CWD pieces based on point-intersect sampling.

lap can be ignored, this estimate of the projected area of an individual piece of CWD is substituted into the appropriate LIS formula and summed.

Following this approach, the total projected area of CWD per hectare based on the i^{th} sample point is determined as:[6]

$$pa_i(m^2/ha) = \frac{50 \times \pi}{L} \sum_{j=1}^{m_i} \frac{d_{ij}}{\cos \lambda_{ij}} \qquad (7)$$

where,

L is the length in m of the transect line at the sample point,

m_i is the number of CWD pieces at the i^{th} sample point,

d_{ij} is the diameter in cm of the j^{th} CWD piece at the point of intersection with the transect line at the i^{th} sample point, and

λ_{ij} (the tilt angle) is the angle in degrees from the horizontal of the j^{th} piece on the i^{th} transect.

If simple random or systematic sampling is used to locate the sample points, the mean and standard error for total projected area can be determined by substituting pa_i for pc_i in formulas 2 and 3. Proportion cover can be estimated as the total projected area per hectare as calculated above, divided by 10 000 m^2 (the area of one hectare).

If there are overlapping pieces and the parameter of interest is the total ground area covered by CWD, rather than the sum of the projected areas of the individual footprints, then it will be necessary to estimate the area where individual CWD pieces overlap and subtract this from the sum of the individual footprint areas. In practice this is difficult and time consuming to do. This approach is therefore best suited where overlap between individual pieces is minimal and can be ignored (otherwise the cover will be overestimated). The advantage of this approach is that individual CWD footprint areas are calculated solely from piece diameters taken at the point where they are crossed by a transect; no additional measurements are required to estimate volume.

Surface area

The surface area[7] of debris pieces may be important when estimating populations of particular insects (e.g., spruce beetle, see Safranyik and Linton 1987 and 2000) or in other situations where an estimate of bark area is needed. Assuming that the CWD pieces are cylindrical, lying horizontal, and are above ground (including any part that is in contact with the ground), the total CWD surface area is:

$$sa_i(m^2/ha) = \frac{50 \times \pi^2}{L} \sum_{j=1}^{m_i} \frac{d_{ij}}{\cos(\lambda_{ij})} \qquad (8)$$

where,

d_{ij} is the diameter of the j^{th} piece at the point it is crossed by the i^{th} transect (cm),

m_i is the number of pieces crossed by the i^{th} transect,

L is the length of the transect line (m), and

λ_{ij} (the tilt angle) is the angle in degrees from the horizontal of the j^{th} piece on the i^{th} transect.

[6] Refer to Marshall et al. 2000 for derivation.

[7] For the purposes of this section, surface area is taken to be that portion of the CWD piece that is or could be covered by bark (i.e., the longitudinal extent of the piece). The areas of both ends of a piece are explicitly excluded. If it is desired to determine the surface areas of pieces including ends, the formula presented for surface area would need to be modified.

Question 3. What measurements are required to estimate the total length of CWD on an area?

Total CWD length per hectare is perhaps the simplest descriptor to determine in the field because it requires only a count of the number of debris pieces crossing a transect line. Total length (m/ha) is calculated as:

$$tl_i(m/ha) = \frac{10000 \times \pi \times \sum_{j=1}^{m_i} \frac{1}{\cos \lambda_{ij}}}{2 \times L} \qquad (9)$$

(Marshall et al. 2000)

where,

m_i is the number of pieces crossed by the i^{th} transect,

λ_{ij} is the angle from horizontal in degrees of the j^{th} piece on the i^{th} transect, and

L is the transect length (m).

The total CWD length per hectare can be estimated for all pieces or for a subpopulation of pieces with specific attributes (e.g., minimum large-end diameter, decay class).

Question 4. How should changes in CWD through time be assessed?

There are a number of situations where it may be desirable to make periodic assessments of CWD (e.g., determination of CWD dynamics, assessing the effects of a particular treatment on CWD quality or quantity). If your primary interest is in estimating the change from one occasion to another, remeasuring samples obtained at the same locations as previous samples is generally the most efficient approach. In terms of LIS, this generally translates into: (1) re-establishing or maintaining the location of at least some of the transect lines originally established across an area, or (2) marking the CWD pieces and locations on each piece, where measurements were taken on the previous occasion. There may be some situations where using both approaches may be helpful.

Re-establishing or maintaining the location of transect lines

This approach is akin to permanent sample plots. It is best suited for assessing changes in CWD quality or quantity over long periods (decades) of time or assessing the effects of various forms of harvesting on the CWD in an area over the long term. If there has been management activity in an area, two kinds of changes are likely: (1) movement of previously downed CWD, and (2) additions and deletions to the CWD pool as a result of the activity. The first kind of change can result in changes to the values for any single transect, but should average out over a very large number of transects (i.e., the expected value of the net effect should be zero, assuming there are no losses or additions due to other causes such as decay or windthrow). The combined effect of the second kind of change is often what is primarily of interest in a study. Unfortunately, variation introduced by the first kind of change can obscure the effect of the second.

One way to address this complication is to have a sufficient number of transects in place to "average out" the effect of piece movement. However, this is seldom possible. Also, all transects should be relocated carefully, to avoid introducing additional variation. This can be achieved by permanently marking transect line locations along their lengths (e.g., every few metres). Care should also be taken in making measurements of the CWD pieces to avoid introducing large amounts of measurement error.[8] If your primary interest is in short-term changes to the CWD population following treatment, you should consider the next approach.

Marking CWD pieces that are measured

This approach is useful if you are interested in following changes in the attributes (decay class, size, etc.) of the CWD pieces that were sampled initially through time. This might be the case, for example, if there was interest in assessing the effects of a prescribed burn on a site. Each piece in the original sample can be marked (e.g., with a common nail) at the point at which diameter was measured on the first occasion. This allows the pieces in the original sample to be relocated and diameters measured at the same points as on the first occasion despite the fact that the pieces may have moved somewhat or the transect line could not be exactly re-established.

FIELD MEASUREMENT QUESTIONS

Question 5. Can the transect length be extended to ensure a minimum number of pieces are sampled?

Changing the lengths of transect lines based on what is found at a location is not a good idea if you wish to obtain unbiased estimates of CWD volume or number of CWD pieces on a per-hectare basis. Similarly, stopping (or extending) sampling on a transect line when (or until) you have reached some target number of pieces that meet a particular criterion (i.e., stopping when you have found exactly three pieces) will lead to biased estimators if a simple random sampling approach is assumed.[9] It is better

[8] Measurement error may reflect various factors, including bias in how measurements are taken, bias in instrumentation, lack of measurement precision, poorly defined measurement standards, and difficulty in applying measurement standards due to object features. In particular, measurements on CWD pieces in decay classes 3–5 (Sollins 1982) can be difficult to reproduce to a high degree of precision. This reflects their semi-round shape and the often soft consistency. Further, because these pieces are in an advanced state of decay, their shapes may well change within a short time.

[9] Where the length of the line transect has been changed based on what is found at the location, distance sampling techniques can be used to analyse the data in certain cases. See, for example, Bachelor and Hodder (1975), Persson (1971), Patil et al. (1979), and Payandeh and Ek (1986) for details on certain distance sampling techniques. However, it is best to avoid this problem in the first place.

to include more transect lines if you wish to measure a particular number of pieces on an area that meet particular criteria. However, adding additional transect lines based on what has been found at a location can lead to biased confidence intervals unless adjustments are made.[10]

The best solution is to pick a sample size and transect length that will yield, roughly, on average, the number of sample pieces with particular characteristics (e.g., diameter >30 cm at the point of intersection) that you would like to have, and live with the fact that sometimes you may find more at a location and sometimes you will find fewer. If prior information about the criteria of interest is unavailable, it may be necessary to undertake a pilot sample to provide a rough estimate of the population characteristics which can then be used in helping choose the length and number of transect lines required for your study.

Question 6. What diameter should be recorded for pieces with butt flare?

In LIS sampling, the diameters[11] of round or semi-round pieces are generally recorded at the point at which the transect line crosses the piece. We suggest that you follow this practice even if you suspect that butt flare is present on a piece. There are two basic reasons for this: one practical and the other theoretical. The practical reason is that there is no clear standard for how far to move the diameter measurement to avoid the butt flare on a piece of downed CWD. The theoretical reason is related to how volumes are determined in so-called solids of revolution.[12] If a piece is shaped exactly like one of the solids of revolution, in order to get an appropriate volume for a piece, the diameters at all points along the length of the piece need to have an equal probability of being crossed by a transect line. This would not hold if the larger diameters associated with butt flare are avoided by measuring diameter above the flare. The net result would be underestimation of the volume of the piece.

DATA COMPILATION QUESTIONS

Question 7. How can volume-per-hectare estimates for round or semi-round pieces and odd-shaped pieces be combined?[13]

Round or semi-round pieces and odd-shaped pieces are commonly classified in the field as separate entities requiring different field measurements. In the case of round or semi-round pieces, piece diameter is measured at the point a piece is crossed by a transect line. These diameters are subsequently used in the standard LIS equations to calculate volume per hectare or biomass per hectare. In the case of odd-shaped pieces, piece diameter is commonly not measured. Instead, volume per hectare may be based on the dimensions of a rectangle (i.e., length and width) with an equivalent cross sectional area to the cross section of the odd-shaped piece.[14] These measurements are taken along the plane formed by the intersection of the transect line with the piece. The rectangular approach is used because it is difficult to define the diameter of an odd-shaped piece.

Because different field measurements are made, round or semi-round and odd-shaped pieces should be compiled initially as separate elements. Separate per-hectare estimates of volume (or biomass) should be made for each of these elements for each transect line (e.g., y_i could be the volume per hectare of round or semi-round pieces based on data collected at transect i, and y_i' could be the volume per hectare of odd-shaped pieces collected at transect i). These estimates can then be averaged over all n transects to produce an overall per-hectare estimate for each component (e.g., $\bar{y}, \bar{y}'$), each with its own standard error ($S_{\bar{y}}, S_{\bar{y}'}$) that depends on the sampling design used, the number of sample points, and the variability of the components in the population. A point estimate for overall volume (or biomass) per hectare can be obtained by adding the means (e.g., $\bar{z} = \bar{y} + \bar{y}'$). The standard error for this combined estimate, assuming simple random or systematic sampling, can be calculated as:

$$S_{\bar{z}}(m^3/ha) = \sqrt{\frac{S_y^2 + S_{y'}^2 + 2\,\mathrm{cov}(y, y')}{n}} \qquad (10)$$

where,

S_y^2 is the estimated variance of the volume per hectare of round/semi-round pieces based on data from each transect,

$S_{y'}^2$ is the estimated variance of the volume per hectare of odd-shaped pieces based on data from each transect, and

$cov(y,y')$ is the covariance of the volume per hectare of round or semi-round pieces and the volume per hectare of odd-shaped pieces based on the data from each transect.

If the rectangular method is used for odd-shaped pieces,

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[10] Adding plots based on what is present is a form of sequential sampling. See Robinson and Burk (1998) for details on the bias that such an approach will cause.

[11] Diameter refers to "equivalent" round diameter. For semi-round pieces this refers to the geometric mean ($\sqrt{h \times w}$) of the height (h) and width (w).

[12] Volumes of solids of revolution are obtained by determining the area under the following equation and rotating it around the x-axis:

$$y = \frac{r_b}{\sqrt{h^p}} \times \sqrt{x^p}$$

where,
y is the radius of a piece at a distance x from the tip,
h is the length of the piece,
r_b is the radius at the base of the piece, and
p is a power that changes for various shapes (for a cylinder, p = 0; or a paraboloid, p = 1; for a cone, p = 2; for a neoloid, p = 3).

[13] CWD pieces must be placed into classes prior to field sampling because different cross sectional shapes require different field measurements in order to obtain accurate estimates of piece volume. CWD pieces are most frequently classified as follows: 1) round or semi-round in cross section; 2) some other cross sectional shape (odd-shaped pieces), and 3) CWD accumulations (Marshall et al. 2000; BC Ministry of Forests 2000a).

[14] See pp. 21-23 in Marshall et al. 2000 for a more detailed explanation.

then a combined estimate of volume per hectare can be calculated only for total volume per hectare. A combined estimate of volume per hectare by diameter class cannot be calculated because the rectangular method does not provide a diameter measurement for odd-shaped pieces.

Question 8. Can the number of CWD pieces per hectare or average length of odd-shaped pieces be calculated?

When using LIS for sampling CWD, it is necessary to know the length of an object in order to determine the probability of that object being intersected by the transect line. It is this probability that allows estimates to be put on a unit area basis (e.g., number of pieces per hectare). It is only in a few special cases, such as volume per hectare, that length "cancels out" of the formula and is not required. An estimate of piece density and/or average length per hectare requires a length measurement on each individual piece irrespective of piece shape.[15]

The paper by Marshall and Davis (2002) reviews approaches for measuring the length of round or semi-round pieces. Measuring the length of odd-shaped pieces is a further challenge. One approach is to determine the "length" of an odd-shaped piece from the length of its "footprint"[16]. The footprint length is the length of the longest axis of the projected area on the ground. It is this axis that must be crossed by the transect line in order for the piece to be included as part of the sample. If the piece has a circular footprint (i.e., horizontal disk lying on the ground), an axis should be established at random. The piece is included in the sample if that axis is crossed by the transect line. The "length" of an odd-shaped piece is not required for determining the volume per hectare associated with such a piece if the rectangular approach is followed. However, piece length will allow the probability of crossing the piece to be determined, and, hence, the total number of such pieces per hectare to be estimated for the area.

If piece length is recorded for both round or semi-round and odd-shaped pieces, a combined estimate of total number of pieces per hectare can be determined using the approach presented in the answer to Question 7.[17] Further, estimates of number of pieces per hectare by length class can also be calculated.

Question 9. How can data be compiled if transects of different lengths are used?

Using transect lines of unequal lengths at various sampling points should be avoided when possible. If they are used, an unbiased estimate of the variance of any CWD estimate cannot be guaranteed. We suggest using horizontal (slope-corrected) distances when establishing transects, to avoid the effect of differing slopes on length of transect line. If the transect line extends outside of the boundary of the area, a "bounce-back" technique[18] could be used to keep line lengths equal.

However, there are many cases where using equal lengths of transect lines lengths is not possible because a portion of the transect line falls into an excluded area (e.g., road, wide stream). In these instances, the actual length of the transect line that is sampled should be recorded and used when determining per-hectare values associated with that sampling point. We recommend using differential weightings based on the length of the transect line when combining the per-hectare estimates from different sampling points to get an overall mean value (estimates from longer transect lines get proportionally more weight).[19]

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[15] The appropriate formula for determining density (number of pieces/ha) based on data collected at a single sample point is:

$$pph_i = \frac{10000 \times \pi}{2 \times L} \times \sum_{j=1}^{m_i} \frac{1}{l_{ij} \times \cos \lambda_{ij}}$$

where,
L_i is the length of the transect line at a sample point,
m_i is the number of CWD pieces at the i^{th} sample point,
l_{ij} is the length of the j^{th} piece on the i^{th} transect, and
λ_{ij} is the (tilt) angle from the horizontal of the j^{th} piece on the i^{th} transect.

See de Vries (1986) or Marshall et al. (2000) for the derivation of this and other LIS formulas.

[16] A footprint is the two-dimensional projection of a piece on a plane.

[17] The formula provided in Footnote 15 can be applied to round or semi-round and odd-shaped pieces separately if it is thought to be important to know the number of pieces per ha of each of these types of pieces. Alternatively, the length and horizontal angle data from both types of pieces can be merged for each sample point, and a single calculation performed.

[18] The "bounce-back" technique is suggested by the VRI sampling protocol (BC Ministry of Forests 2000a). "It involves doubling back along a transect line from the point at which it intersects the sample target (e.g., polygon) boundary, until the appropriate length of transect line is reached. Each transect piece that is crossed a second time is counted as an additional observation. If the boundary is intersected before the halfway point of the transect line, the bounce-back extends back past the point of origin of the transect line." (Marshall et al. 2000, p. 14)

[19] Weights can be determined as:

$$w_i = \frac{L_i}{\left(\sum_{i=1}^{n} L_i\right) / n}$$

where,
L_i is the length of the i^{th} transect line.
The weighted mean value is:

$$\bar{y} = \frac{\sum_{i=1}^{n} (w_i \times y_i)}{n}$$

where,
y_i is the per-ha value associated with the ith transect.
The standard error for the weighted mean is:

$$S_{\bar{y}} = \sqrt{\frac{\sum_{i=1}^{n} w_i \times (y_i - \bar{y})^2}{(n-1) \times n}}.$$

CONCLUDING COMMENTS

Line intersect sampling (LIS) is not a fixed body of measurement rules, but rather an efficient and flexible sampling technique that can be used to estimate a wide number of descriptors of downed CWD. The sampling design, intensity, layout, field measurements, and compilation procedures can be varied depending on the required precision, the woody debris descriptors of interest, and how the data are to be reported. An understanding of the theory as well as the practical questions that arise allows users to adapt their methods to the survey objectives and field conditions.

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REFERENCES

Batchelor, C.L. and R.A.C. Hodder. 1975. "Tests of Distance Techniques for Inventories of Pine Plantations" in *New Zealand Journal of Forest Sciences* 5:3–17.

BC Ministry of Forests. 2000a. *Vegetation Resources Inventory Ground Sampling Procedures*. Resources Inventory Branch, Victoria. 313 pp.

————. 2000b. *Cruising Manual*. Resources Inventory Branch, BC Ministry of Forests, Victoria.

Brown, J.K. 1974. *Handbook for Inventorying Downed Woody Material*. Intermountain Forest and Range Experiment Station, Forest Service, USDA. General Technical Report INT-1. 24 pp.

Cochran, W.G. 1977. *Sampling Techniques*. Third Edition. John Wiley & Sons, New York. 428 pp. (Chapter 5 deals specifically with stratified random sampling.)

de Vries, P.G. 1986. *Sampling Theory for Forest Inventory*. Springer-Verlag, New York. 399 pp. (Chapter 13 deals specifically with LIS)

Freese, F. 1971. *Elementary Forest Sampling*. Forest Service, USDA. Agriculture Handbook No. 232. 91 pp.

Hardy, C.C. 1996. *Guidelines for Estimating Volume, Biomass, and Smoke Production for Piled Slash*. Pacific Northwest Research Station, Forest Service, USDA. General Technical Report PNW-GTR-364. 17 pp.

Hazzard, J.W. and S.G. Pickford. 1986. "Simulation Studies on Line Intersect Sampling of Forest Residue. II" in *Forest Science* 32:447–470.

Howard, J.O. and F.R. Ward. 1972. *Measurement of Logging Residue—Alternate Applications of the Line Intersect Method*. Forest Service, USDA. Research Note PNW-183. 8 pp.

Little, S.N. 1982. *Estimating the Volume of Wood in Large Piles of Logging Residue*. Pacific Northwest Research Station, Forest Service, USDA. Admin. Report PNW-1. 7 pp.

Kaiser, L. 1983. "Unbiased Estimation in Line-Intercept Sampling" in *Biometrics* 39:965–976.

Lucas, H.A. and G.A.F. Seber. 1977. "Estimating Coverage and Particle Density Using the Line Intercept Method" in *Biometrika* 64:618–622.

Marshall, P.L. and G. Davis. 2002. *Measuring the Length of Coarse Woody Debris*. Research Section, Vancouver Forest Region, BC Ministry of Forests, Nanaimo. Extension Note EN-011. 8 pp.

Marshall, P.L.; G. Davis; and V.M. LeMay. 2000. *Using Line Intersect Sampling for Coarse Woody Debris*. Research Section, Vancouver Forest Region, BC Ministry of Forests, Nanaimo. Technical Report TR-003. 34 pp.

Nemec, A.F. and G. Davis. 2002. *Efficiency of Six Line Intersect Sampling Designs for Estimating Volume and Density of Coarse Woody Debris*. Research Section, Vancouver Forest Region, BC Ministry of Forests, Nanaimo. Technical Report TR-021. 12 pp.

Patil, S.A.; K.P. Burnham; and J.L. Kovner. 1979. "Nonparametric Estimation of Plant Density by the Distance Method" in *Biometrics* 35:243–248.

Payandeh, B. and A.R. Ek. 1986. "Distance Methods and Density Estimators" in *Canadian Journal of Forest Research* 16:918–824. (See errata *Canadian Journal of Forest Research* 17:95–96)

Persson, O. 1971. "The Robustness of Estimating Density by Distance Measures" pp. 175–190 in *Statistical Ecology, Volume 2*. G.P. Patil, E.C. Pielou, and W.E. Walters (editors). Pennsylvania State University Press.

Robinson, A.P. and T.E. Burk. 1998. "Sequential Sampling of Normal and Non-Normal Populations" in *Canadian Journal of Forest Research* 28:660–664.

Safranyik, L. and D.A. Linton. 1987. *Line Intersect Sampling for the Density and Bark Area of Logging Residue Susceptible to the Spruce Beetle, Dendroctonus rufipennis (Kirby)*. Pacific Forestry Centre, Canadian Forest Service. BC-X-295. 10 pp.

————. 2000. *Using Line Intersect Sampling to Predict Spruce Beetle Populations in Logging Residue*. Pacific Forestry Centre, Canadian Forest Service. Technical Transfer Note 23. 4 pp.

Sollins, P. 1982. "Input and Decay of Coarse Woody Debris in Coniferous Stands in Western Oregon and Washington" in *Canadian Journal of Forest Research* 12:18–28.

Taylor, S.W. 1997. *A Field Estimation Procedure for Downed Coarse Woody Debris*. Pacific Forestry Centre, Canadian Forest Service. Technical Transfer Note #2. 6 pp.

Van Wagner, C.E. 1968. "The Line-Intersect Method in Forest Fuel Sampling" in *Forest Science* 14:20–26.

Appendix A

Equations for Using LIS to Estimate Some Common CWD Descriptors for Round and Semi-Round Pieces

Attribute	Assuming pieces lie horizontal		Including influence of tilt angle	
Total volume (m^3/ha)	$v_i = \frac{\pi^2}{8 \times L} \sum_{j=1}^{m_i} d_{ij}^{\,2}$	(1a)	$v_i = \frac{\pi^2}{8 \times L} \sum_{j=1}^{m_i} \frac{d_{ij}^{\,2}}{\cos \lambda_{ij}}$	(1b)
Total density (no. pieces/ha)	$pph_i = \frac{10000 \times \pi}{2 \times L} \times \sum_{j=1}^{m_i} \frac{1}{l_{ij}}$	(2a)	$pph_i = \frac{10000 \times \pi}{2 \times L} \times \sum_{j=1}^{m_i} \frac{1}{l_{ij} \times \cos \lambda_{ij}}$	(2b)
Total piece length (m/ha)	$tl_i = \frac{10000 \times \pi}{2 \times L} \times m_i$	(3a)	$tl_i = \frac{10000 \times \pi}{2 \times L} \times \sum_{j=1}^{m_i} \frac{1}{\cos \lambda_{ij}}$	(3b)
Total projected area (m^2/ha)	$pa_i = \frac{50 \times \pi}{L} \sum_{j=1}^{m_i} d_{ij}$	(4a)	$pa_i = \frac{50 \times \pi}{L} \times \sum_{j=1}^{m_i} \frac{d_{ij}}{\cos \lambda_{ij}}$	(4b)
Total surface area (m^2/ha)	$sa_i = \frac{50 \times \pi^2}{L} \sum_{j=1}^{m_i} d_{ij}$	(5a)	$sa_i = \frac{50 \times \pi^2}{L} \times \sum_{j=1}^{m_i} \frac{d_{ij}}{\cos \lambda_{ij}}$	(5b)
Biomass (t/ha)	$b_i = v_i \times \overline{RD}$	(6a)	$b_i = v_i \times \overline{RD}$	(6b)
Percent cover (%)	$pc_i = \frac{LC_i}{L} \times 100$	(7a)	$pc_i = \frac{LC_i}{L} \times 100$	(7b)
Average piece length (m)	$\bar{l}_i = \frac{m_i}{\sum_{j=1}^{m_i} \frac{1}{l_{ij}}}$	(8a)	$\bar{l}_i = \frac{\sum_{j=1}^{m_i} \frac{1}{\cos \lambda_{ij}}}{\sum_{j=1}^{m_i} \frac{1}{l_{ij} \times \cos \lambda_{ij}}}$	(8b)
Average piece volume (m^3)	$\bar{v}_i = \frac{v_i}{pph_i}$	(9a)	$\bar{v}_i = \frac{v_i}{pph_i}$	(9b)
Average piece diameter (cm)	$\bar{d}_i = \frac{\sum_{j=1}^{m_i} \frac{d_{ij}}{l_{ij}}}{\sum_{j=1}^{m_i} \frac{1}{l_{ij}}}$	(10a)	$\bar{d}_i = \frac{\sum_{j=1}^{m_i} \frac{d_{ij}}{l_{ij} \times \cos \lambda_{ij}}}{\sum_{j=1}^{m_i} \frac{1}{l_{ij} \times \cos \lambda_{ij}}}$	(10b)

Symbols Used in the Equations

b_i Estimate of biomass per hectare based on the i^{th} transect (t/ha).

d_{ij} Diameter of the j^{th} piece in the i^{th} transect at the point of intersection (cm).

$\bar{d}_i$ Estimate of average piece diameter based on the i^{th} transect (cm).

λ_{ij} Angle subtended by the j^{th} piece on the i^{th} transect and a horizontal plane (degrees).

l_{ij} Length of the j^{th} piece in the i^{th} transect (m).

$\bar{l}_i$ Estimate of average length of CWD pieces based on the i^{th} transect (m).

L Transect length (m).

LC_i Length of the i^{th} transect intersected that crosses CWD pieces (m).

m_i Number of CWD pieces intersected by the i^{th} transect.

pa_i Estimate of the projected area of CWD pieces based on the i^{th} transect (m^2/ha).

pc_i Estimate of the percent cover based on the i^{th} transect.

pph_i Estimate of the number of CWD pieces per hectare based on the i^{th} transect (density).

$\overline{RD}$ Average relative density of a CWD piece.

sa_i Estimate of the surface area of CWD pieces based on the i^{th} transect (m^2/ha).

tl_i Estimate of the total length of CWD based on the i^{th} transect (m/ha)

v_i Estimate of volume per hectare based on the i^{th} transect (m^3/ha).

$\bar{v}_i$ Estimate of average piece volume based on the i^{th} transect (m^3).